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R-parity Violating Radiative Photino Decay in Supersymmetric Models

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It has been shown that unless the tri-linear R-parity violating coupling λ_{i33} (i = 1, 2) is small enough ($\lambda_{i33} < 10^{-2}$ for MSSM and 10^{-3} for GMSB model), the partial decay width of photino decaying into 'photon + $\nu_{e,\mu}$', both in supergravity motivated (MSSM) and gauge mediated (GMSB) supersymmetric models are larger than the partial decay width of photino decaying into 'photon + goldstino' in R-parity conserving GMSB model including one loop supersymmetric QED correction.

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Confirmation of neutrino oscillation by Superkamiokande experiment [1] leads to the conclusion of non-zero neutrino mass. In Minimal Supersymmetric version of Standard Model either Supergravity motivated (we refer it as MSSM) [2] or Gauge mediated (which we refer as GMSB) [3], this feature of non-zero neutrino mass is realized through R- parity violation in the theory. Supersymmetric models with R parity violation opens up a plethora of new signals or can mimic the signals of R- parity conserving models. In the present work, we have computed such loop induced photino decays [4] $\tilde{\gamma} \rightarrow \gamma\nu_e$, $\tilde{\gamma} \rightarrow \gamma\nu_\mu$ via R- parity violation. The qualitative nature of both these processes are same and the quantitative difference arises due to the difference in respective R-parity violating couplings. Keeping this feature in view, in the following, we represent both the decays as $\tilde{\gamma} \rightarrow \gamma\nu_i$ (where $i = e, \mu$) and the decay amplitude of both the processes will be evaluated just by replacing the respective R-parity violating coupling. Furthermore, we have neglected the decay process $\tilde{\gamma} \rightarrow \gamma\nu_\tau$ as it is much suppressed compared to the other two processes. This is precisely because $\tilde{\gamma} \rightarrow \gamma\nu_i$ decays involve heaviest τ lepton in the loop whereas $\tilde{\gamma} \rightarrow \gamma\nu_\tau$ decay involves e and μ leptons. The decay $\tilde{\gamma} \rightarrow \gamma\nu_i$ mimics the signal of $\tilde{\gamma} \rightarrow \gamma\tilde{G}$ in R-parity conserving GMSB model where $\tilde{\gamma}$ is the Next to Lightest Supersymmetric Particle (NLSP). Both these decay process , $\tilde{\gamma} \rightarrow \gamma\nu_i$ and $\tilde{\gamma} \rightarrow \gamma\tilde{G}$, give rise to the same final state "$\gamma + \not{E}$ ". We have also considered one loop supersymmetric QED correction of the decay $\tilde{\gamma}\rightarrow \gamma\tilde{G}$. There is not much enhancement in the partial decay width due to this correction and we find that the partial decay width of $\tilde{\gamma} \rightarrow \gamma\nu_i$ decay process is larger than the $\tilde{\gamma} \rightarrow \gamma\tilde{G}$ decay, unless the trilinear λ_{i33} (where i = 1, 2) coupling is too small. Furthermore, if R parity is violated , there will be possible three body photino decay ($\tilde{\gamma} \to fff$) and it has been shown [5] that non-observation of such signal put a stringent constraint on the trilinear R-parity violating coupling $< 10^{-5}$, through the comparison between the partial decay width of $\tilde{\gamma} \to \gamma \tilde{G}$ with $\tilde{\gamma} \to fff$. A recent analysis [6] in this path has been done through the inclusion of bi-linear R-parity violating term and it has been shown that the branching ratio of $\tilde{\chi}_1^0 \to \nu\gamma$ decay can have a maximum value of about 5 - 10%. In the present work, we find that the tri-linear R-parity violating λ_{i33} coupling alone give rise to a larger partial decay width of the decay process $\tilde{\gamma} \to \gamma\nu_i$ compared to the one loop supersymmetric QED corrected decay process $\tilde{\gamma} \to \gamma\tilde{G}$, unless the value of λ_{i33} is too low. Thus, if R-parity is violated, ambiguity arises to interpret the observed signal "$\gamma + \not{E}$ " or "$\gamma\gamma + \not{E}$ etc. [7],[8] as a low energy signature of R-parity conserving GMSB model in an unambiguous way. Some other complementary signal in collider experiment should be needed which when taken into account with the "photon + missing energy " signal could lead us to confirm any of these models. Before going into the details, we like to mention the followings: First, although, in general, lightest neutralino $\tilde{\chi}_1^0$ is an admixture of the neutral gauginos and neutral Higgsinos, however, the present state of knowledge leads to the fact that the $\tilde{\gamma}$ component is dominated over the largest region of allowed parameter space [9]. The relevant mixing factor arises due to general consideration of $\tilde{\chi}_1^0$ structure will modify equally all the decays discussed in the present work. Second, we discard any photino-lepton-slepton off diagonal coupling in the present work.

To compute one loop supersymmetric QED correction to the decay of

$\tilde{\gamma} \rightarrow \gamma\tilde{G}$ in R-parity conserving GMSB model, we consider the following goldstino-lepton-slepton interaction Lagrangian [10]

$$L = -ie_{gL}\sqrt{2}[\bar{e_L}\tilde{e_L}\tilde{G} + \bar{\tilde{G}}\tilde{e_L}^{\star}e_L] + ie_{gR}\sqrt{2}[\bar{e_R}\tilde{e_R}\tilde{G} + \bar{\tilde{G}}\tilde{e_R}^{\star}e_R] \qquad (1)$$

where

$$e_{gL} = \frac{m_{\tilde{e_L}}^2 - m_e^2}{d}, e_{gR} = \frac{m_{\tilde{e_R}}^2 - m_e^2}{d}, d = \sqrt{\frac{3}{4\pi}}M_{Susy}^2 \qquad (2)$$

In the above expressions $m_{\tilde{e_L}}$, $m_{\tilde{e_R}}$ are the masses of the left-slepton and right-slepton and M_{Susy} is the supersymmetry breaking scale parametrized in terms of parameter d. In GMSB model, masses of left-slepton and right-slepton are wide apart primarily due to their different representation under SU(2) gauge group and since $m_{\tilde{e_L}} >> m_{\tilde{e_R}}$ we have discarded the contribution due to $m_{\tilde{e_L}}$. Furthermore, we ignored any non-degeneracy in right-slepton masses and $m_{\tilde{e_R}}$ represents mass of the right-selectron. The one loop supersymmetric QED corrected diagrams of the decay $\tilde{\gamma}(q) \rightarrow \gamma(p_2)\tilde{G}(p_1)$ is generated due to slepton- lepton particles in the loop. The squark-quark induced loop diagrams are neglected since $m_{\tilde{q}} >> m_{\tilde{l}}$. Neglecting lepton masses as well compared to selectron mass, we obtain the following matrix element

$$-iM_{loop} = i(\frac{2e^2}{16d\pi^2})m_{\tilde{e_R}}^2 A\bar{u}(p_1)\gamma^{\rho}u(q)\epsilon_{\rho}^{\star} \qquad (3)$$

where

$$A = -\frac{3}{2}\ln(1 + p - 2p^2) + \frac{p}{18} + \frac{143}{60}p^2 \qquad (4)$$

and $p = \frac{{m_{\tilde{\gamma}}}^2}{{m_{\tilde{e_R}}}^2}$ where $m_{\tilde{\gamma}}$ is the mass of the photino. It is to be noted that as $p \rightarrow 0$, still there is a non-zero contribution to the loop correction due to the presence of the second term in the right-hand side of Eqn.(4), which shows non-decoupling effect of the above process. This is basically due to the proportionality of the coupling of the Goldstino-lepton-slepton term in the lagrangian with the slepton mass squared.

The relevant part of the Lagrangian required to calculate tree level $\tilde{\gamma}(q) \rightarrow \gamma(p_2)\tilde{G}(p_1)$ is given by [11]

$$L = \frac{1}{2d}\partial_\mu \bar{\tilde{\gamma}}\gamma^\mu[\gamma^\nu, \gamma^\rho]\tilde{G}\partial_\nu A_\rho + h.c. \tag{5}$$

and the tree level matrix element comes out as

$$-iM_{Tree} = i\frac{3m_{\tilde{\gamma}}^2}{2d}\bar{u}(p_1)\gamma^\rho u(q)\epsilon_\rho^\star(p_2) \tag{6}$$

The total matrix element M_{total} (= tree level + one loop) of the decay process $\tilde{\gamma} \rightarrow \gamma\tilde{G}$ can be written as

$$M_{total} = M_{tree}(1+\Delta) = \frac{3m_{\tilde{\gamma}}^2}{2d}(1+\frac{e^2}{12\pi^2}\frac{m_{\tilde{e_R}}{}^2}{m_{\tilde{\gamma}}^2}A)\bar{u}(p_1)\gamma^\rho u(q)\epsilon_\rho^\star(p_2) \tag{7}$$

where $\Delta = \frac{M_{loop}}{M_{tree}}$ is the enhancement factor. For a typical mass value of $m_{\tilde{\gamma}}$ = 80 GeV and $m_{\tilde{e}_R}$ = 100 GeV which are allowed in GMSB model, we found the enhancement in M_{total} due to one loop correction is $\Delta \sim 6 \times 10^{-3}$ for three generations of leptons. For higher values of photino and right-selectron masses the correction becomes more and more insignificant. Thus , we find that the enhancement due to the one loop supersymmetric QED correction of the decay $\tilde{\gamma} \rightarrow \gamma\tilde{G}$ is insignificant compared to its tree level decay mode.

Next, we consider the one loop decay of $\tilde{\gamma} \rightarrow \gamma\nu_i$ in MSSM induced by the tri-linear R-parity violating λ_{i33} coupling. The relevant diagrams are obtained by replacing goldstino field of the previous process by the ν_i field with R parity violating λ_{i33} coupling, however, unlike the previous case, there is a chirality flip in the internal lepton(s) line(s) due to Yukawa type nature of the R-parity violating interactions, and therefore, we cannot neglect lepton mass in this case. We have considered heaviest τ lepton contribution only and as we have considered photino-lepton-slepton flavour diagonal coupling, the other particle circulating in the loop is $\tilde{\tau_R}$. Furthermore, we have ignored any non-degeneracy between $m_{\tilde{\tau_L}}$ and $m_{\tilde{\tau_R}}$ and we have also ignored λ' coupling induced $d - \tilde{d}$ interactions by considering $m_{\tilde{d}} >> m_{\tilde{\tau}_R}$.

We consider the following R-parity violating trilinear interaction,

$$L_{\not R_p} = \frac{\lambda_{i33}}{2}[\tilde{\tau_L}\nu_{iL}\bar{\tau_R} + (\tilde{\tau}_R)^\star\, \bar{(\nu_{iL})^c}\, \tau_L] + h.c. \tag{8}$$

The squared matrix element of the process $\tilde{\gamma} \rightarrow \gamma\nu_i$ comes out as

$$|M|^2{}_{MSSM} = 16Q^2[2A^2 - B_1{}^2(A_1 + C)(B + C) - 2AB_1(B + C)] \tag{9}$$

where

$$Q = (\frac{\lambda_{i33}\alpha}{4\sqrt{2}\pi})(\frac{m_\tau}{m^2_{\tilde{\tau}}})m^2_{\tilde{\gamma}} \tag{10}$$

$$A = \frac{t}{t-1}\ln t - \ln t - 1 \tag{11}$$

$$A_1 = \frac{2}{1-t}(t\ln t + 1 - t) - 1 + \frac{2}{(1-t)^2}(\frac{t^2}{4} - \frac{1}{4} - \frac{t^2}{2}\ln t) \tag{12}$$

$$B = \frac{t}{1-t}\ln t + 1 \tag{13}$$

$$B_1 = \frac{3}{t-1} \tag{14}$$

$$C = \frac{1}{(1-t)^2}[t(1 - \frac{t}{2})\ln t + (t - \frac{1}{4}) - \frac{3t^2}{4}] \tag{15}$$

and $t = \frac{m_\tau^2}{m_{\tilde{\tau}}^2}$. Neglecting higher powers of t , we obtain a simpler expression for ${|M|^2}_{MSSM}$ as

$$ {|M|^2}_{MSSM} = 16Q^2[2(1+\ln t)^2 + \frac{9}{2}\ln t + \frac{45}{16}] \tag{16} $$

The partial decay width comes out as

$$ \Gamma_{\not R_p}^{MSSM} = \frac{1}{16\pi}{|M|^2}_{MSSM}\frac{1}{m_{\tilde{\gamma}}}. \tag{17} $$

The partial decay width $\Gamma(\tilde{\gamma} \to \gamma\tilde{G})$ in R-parity conserving GMSB model at the tree level is given by [12]

$$ {\Gamma(\tilde{\gamma} \to \gamma\tilde{G})}^{GMSB} = \frac{m_{\tilde{\gamma}}^5}{6M_{Susy}^4} \tag{18} $$

and for the previous choice of photino mass and $M = 150$ TeV , the partial decay width comes out as ${\Gamma(\tilde{\gamma} \to \gamma\tilde{G})}^{GMSB} \sim 0.10 \times 10^{-11}$ whereas $\Gamma_{\not R_p}^{MSSM} \sim 0.17 \times 10^{-7} \times \lambda_{i33}^2$ for $m_{\tilde{\tau}} = 200$ GeV , $m_{\tilde{\gamma}} = 100$ GeV. Thus , unless λ_{i33} is very small ($< 10^{-2}$), $\Gamma(\tilde{\gamma} \to \gamma\nu_i)_{\not R_p}^{MSSM} > \Gamma(\tilde{\gamma} \to \gamma\tilde{G})^{GMSB}$. Such a value of λ_{i33} is well within the present upper bounds : $\lambda_{233} < 0.09(\frac{m_{\tilde{\tau}}}{100\text{GeV}})$, $\lambda_{133} < 0.24(\frac{m_{\tilde{\tau}}}{100\text{GeV}})$ [13].

Similar result is also obtained in case of GMSB model including R-parity violation. The squared matrix element in this case is given by

$$ {|M|^2}_{GMSB} = 4{(\tfrac{\lambda_{i33}\alpha}{4\sqrt{2\pi}})}^2 t_1[2(1+\ln t_1)^2 + \tfrac{9}{2}\ln t_1 + \tfrac{45}{16}]\frac{m_{\tilde{\gamma}}^4}{m_{\tilde{\tau}_R}^2} \tag{19} $$

$$ +\text{terms containing } m_{\tilde{\tau}_L} \tag{20} $$

where $t_1 = \frac{m_\tau^2}{m_{\tilde{\tau}_R}^2}$ and as before we have neglected higher powers of t_1. We can also neglect left-slepton contribution in the above expression since $m_{\tilde{\tau}_L} >> m_{\tilde{\tau}_R}$ in GMSB model. The partial decay width comes out as

$$ \Gamma_{\not R_p}^{GMSB} = \frac{1}{16\pi}{|M|^2}_{GMSB}\frac{1}{m_{\tilde{\gamma}}}. \tag{21} $$

For a typical choice of model parameters, $m_{\tilde{\gamma}} = 80$ GeV , $m_{\tilde{\tau}_R} = 100$ GeV we obtain, $\Gamma^{GMSB}_{\not{R}_p} = 0.21{\times}10^{-7}{\times}{\lambda_{i33}}^2$. Hence , as before , unless $\lambda_{i33} < 10^{-3}$, the partial decay width of R-parity violating photino decay ($\tilde{\gamma} \rightarrow \gamma\nu_i$) in GMSB model is larger than the R- parity conserving photino deacy ($\tilde{\gamma} \rightarrow \gamma\tilde{G}$) mode.

In summary, we have calculated partial decay width of one loop radiative photino decay ($\tilde{\gamma} \rightarrow \gamma\nu_i$) (where $i = e, \mu$) both in MSSM as well as GMSB models due to tri-linear R-parity violating interactions. We have also computed one loop supersymmetric QED corrected amplitude of the decay process $\tilde{\gamma} \rightarrow \gamma\tilde{G}$ in R-parity conserving GMSB model. We found that for a typical choice of model parameters the enhancement due to this correction , $\Delta(=\frac{M_{loop}}{M_{tree}})$ is of the order of 6×10^{-3} for three generations of leptons. We have compared the one loop QED corrected partial decay width of the decay $\tilde{\gamma} \rightarrow \gamma\tilde{G}$ with the R-parity violating $\tilde{\gamma} \rightarrow \gamma\nu_i$ decay for both MSSM and GMSB models and we found that unless the tri-linear R-parity violating λ_{i33} (where $i = 1, 2$) coupling is small enough ($\lambda_{i33} < 10^{-2}$ for MSSM and 10^{-3} for GMSB model), the partial decay width of this loop induced process is larger than the photino decay $\tilde{\gamma} \rightarrow \gamma\tilde{G}$ in R-parity conserving GMSB model. The upshot of this analysis leads to a crucial position to interpret the collider signal "photon + missing energy" as a signature of R-parity conserving GMSB model in an unambiguous way.

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